LU-176

Preliminary Analysis of Linac Upgrade Quad

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Apparatus:

The measurement system consists of a Morgan coil with coils for N = 1 - 7. The signals from the coil along with the current signal from the power supply go to a LeCroy 6810 4-channel waveform digitizer. This is connected by CAMAC to a PC. The probe is rotated by a stepping motor with encoder readback. The PC runs a program that mimics an ACNET console. An application program has been written to perform the measurement runs.

The operator starts the application program and chooses the number of points to measure in a full revolution and which signals are to be digitized by the 6810. The computer steps the probe to position and arms the 6810. Trigger pulses to the quad power supply are fanned out to the 6810 to trigger it. Four samples of each of the four signals are recorded. This allows signal averaging for the weaker signals however it was found that this was not necessary. The screen of the computer monitors the integrals of the signals, the position of the probe, and the step counts sent and received for the latest step. At the end of a full revolution, half of the points have been measured. The probe is rotated in the reverse direction for half a normal increment and the process repeats in the reverse direction with the points taken halfway between the first set. This helps monitor any drift in the power supply output. At the end of the run, each of the signals are plotted on the screen as a function of the rotation angle.

Measurement technique:

The signal from the coil goes to the Lecroy 6810. The signal from time = t_quad is digitized at 1MHz for 1000 samples. This goes slightly past the first 90 degrees of the signals (see figure 1). The waveforms were numerically integrated from the start of the rise to the peak. The value of the integrals are written to disk along with the angle at which the reading occurred. One hundred and twenty eight points are taken for a full revolution. The probe is rotated in one direction while 64 points are taken and the reversed for another 64 that are taken half way between the previous points.

These data are transferred to ADCALC for offline analysis. Each record consists of the probe angle and the integrals of the current, the quadrupole coil and two other coils. Offline, the current for a run is averaged and all the coil signals are normalized to that average to correct for any drift. Then the signals as a function of angle are sent to a Fast Fourier Transform to give the amplitudes of the harmonic components.

Effects of the beam pipe:

The possibility of the beam pipe effecting the quality of the magnetic field was studied while the measurement system was being developed with a DTL quad. Runs were made with the beam pipe in place and with it removed. Also the weld seam in the pipe was rotated to various angles. While the shape of the signal pulse changed when the beam pipe was inserted, no change was observed in the dependence of the signal area as a function of the probe rotation. The seam orientation also had no observable effect.

Focusing strength:

The first criterion that the new magnet must meet is that it must provide the proper focusing power. The optics simulations used in designing the new linac assumed a quadrupole gradient of 23 T/m over 8 cm or 1.84 T-m/m. From the flux as measured by the morgan coil and the coil radius we obtain a value for the gradient times length for the new quad of 1.76 T-m/m at 170 amps. To reach the target of 1.84 the current would need to be raised to 178 amps. The quad has been run up to 200 amps at this point.

Harmonic analysis:

The second criterion for evaluating the magnet is the harmonic quality. Table 1 shows the results of the harmonic analysis for each of the coils. Each column is the result of the Fast-Fourier Transform of the signal from a coil. Each row is a Fourier component ranging from dipole to 60-pole. All values are referenced to the quad component of the quad coil which is given a value of 10000. Figure 2 is the same data in a graphical format. The top portion of table 1 shows the harmonic content at the probe radius of 1.59 cm. The lower portion is renormalized to 1 cm. After renormalization, the only component remaining is 36 parts in 10000 of sextupole. This is higher than our target of 10 parts but that target was chosen to be quite conservative. Thirty-six parts should be fine for a linac component. Also, further studies into end fields may show ways to reduce it.

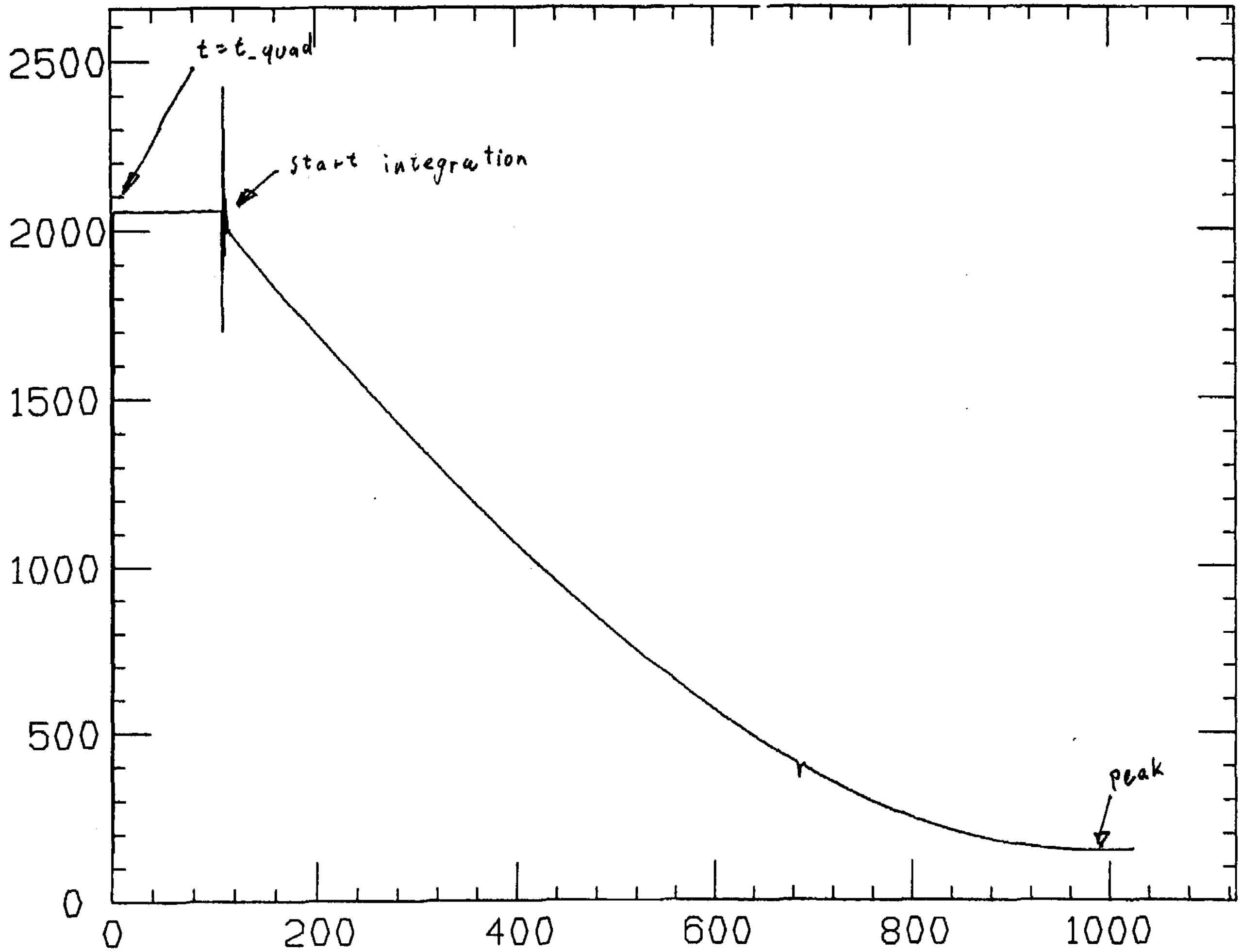
Measuring the end fields:

The end fields were measured by performing measurement runs with the morgan coil inserted into the magnet at various depths. In this way we measured the integral of the field in z from "infinity" to some depth (see figure 3). Due to the setup of the probe, it can only be withdrawn to the point where the field is at the 5% level. Also going beyond this would start to introduce noise problems. To counter this the magnet was turned 180 degrees and the procedure was repeated. The results of this are the x's and diamonds in figure 4. Thirteen runs runs were conducted with the probe centered on the magnet. The average of these measurements of the total integrated field was 888.42×10^{-6} volt-sec. In figure 4 the values represented by diamonds were subtracted from 888.42 in order to continue the curve as if the probe had been continuously removed in one direction. The six points at either end were placed there manually to represent the total integral values for the fit. The solid line is a cubic spline least squares fit to the data and the dashed curve is the first derivative. Due to the nature of spline fits and their response to the placement of the knots, these two curves should be considered to be representative of the integral curve and the field curve and in fact the knots were moved to give a first derivative that matched the central field as determined by a manner to be described in a moment.

Figure 5 shows the measured values between $\pm$ 3 cm of the center of the magnet. Table 2 shows the results of a fit to the points for the intervals $\pm$ .5, 1., 1.5, 2., 2.5, and 3. We feel that this gives a more accurate view of the behavior of the field at that point than as represented by the cubic spline fit. We choose the value of the slope for nine points in the interval $\pm$ 2 based on the chi-squared per degree of freedom, the error on the slope and its linear correlation function, and the multiple correlation function. This value, 104.197 when divided into the field integral of 888.42 gives an effective length of 8.53 $\pm$ .1cm. For the error of the field integral we use the standard deviation of the 13 full field integrals which is 4.167×10^{-6} volt-sec.

Figure 6 shows the variation of the sextupole field in the same manner as figure 5 did for the quadrupole field. The lines do not represent any sort of fit; they just join the points. The solid and dashes separate the two different directions that the probes were removed. Obviously the jump in the set identified by the dashed line is very interesting. It appears that it is real. The different plot symbols note the dates on which the points were taken. Within these dates, the points were taken in somewhat random order. The jump is distributed throughout those dates. It is not due to an error is measuring the position of the probe nor an error in the current. The dashed points were taken such that as the probe was withdrawn, it measured less and less of the magnet field and yet was still measuring whatever field was produced by the current leads (figure 7a). With the magnet reversed, the solid line, the contribution from the leads is the first thing to be eliminated (figure 7b). In the steeply sloping area, only the magnet itself is being measured. This phenomenon will have to be pursued further.

Since each run takes a half hour to perform, the end field measurements are done with only one run each. This gives the operator a choice of what coils are to be monitored. Normally these are the current, the quadrupole, the dipole, and the sextupole. For the last set of z runs, the octupole was substituted for the dipole. Its results are shown in figure 8. The signal is not very large and its distribution is not very enlightening.



t=t_quad
start integration
peak
2500
2000
1500
1000
500
0
0
200
400
600
800
1000

figure 1

NRM2A.DAT ,NRM2B.DAT ,NRM2C.DAT 13-NOV-1990 12:55

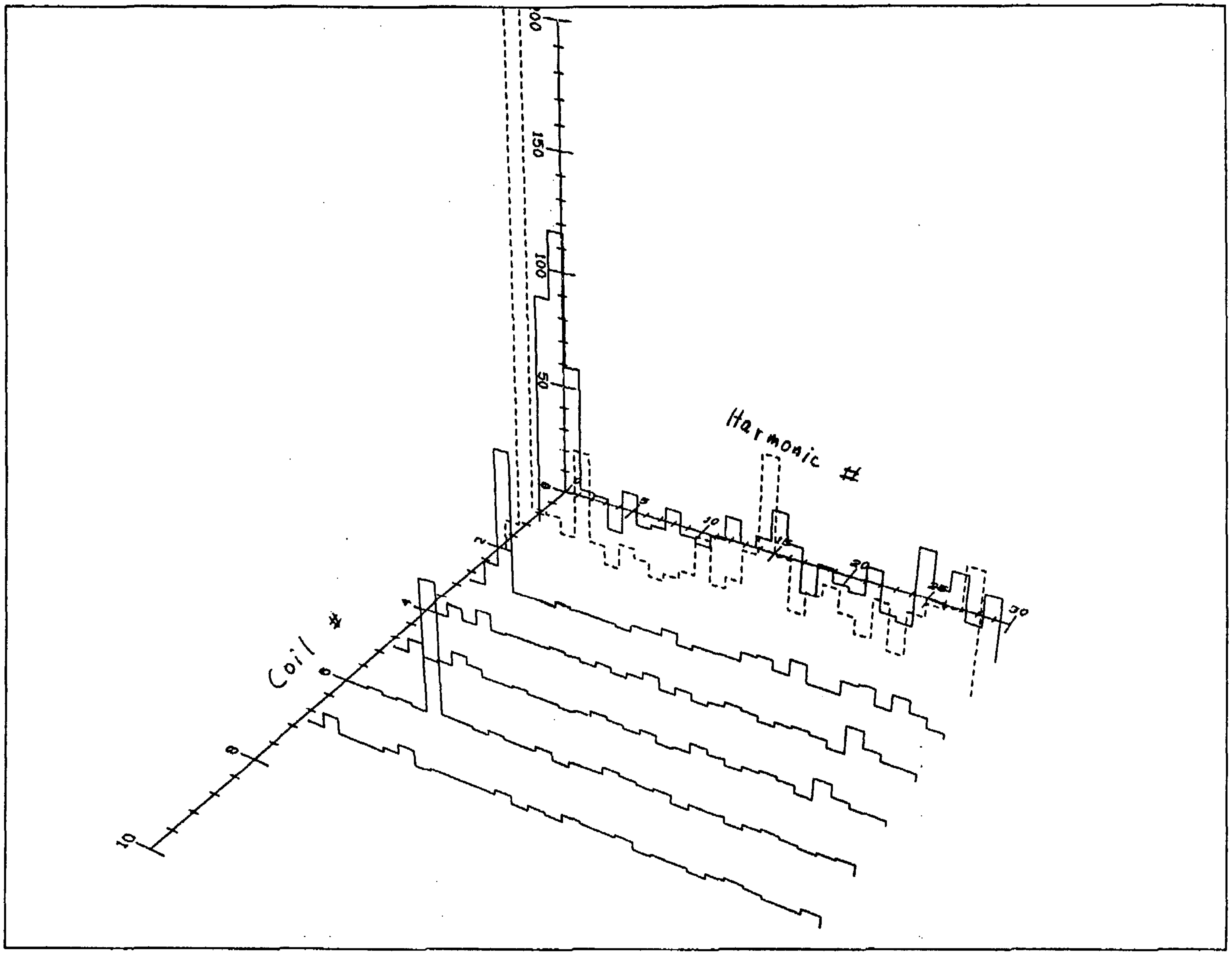


figure 2

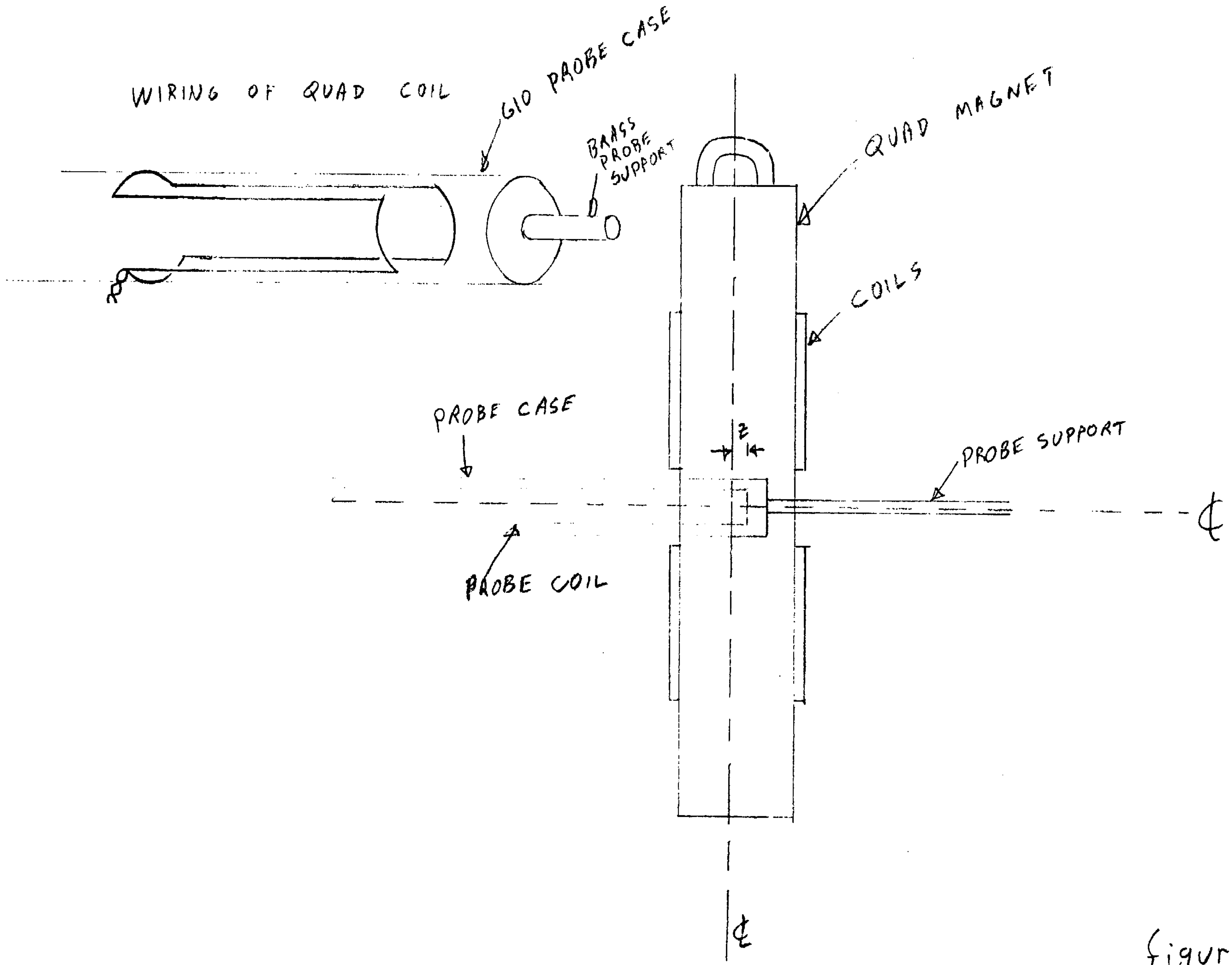

WIRING OF QUAD COIL
G10 PROBE CASE
BRASS PROBE SUPPORT
QUAD MAGNET
COILS
PROBE CASE
Z
PROBE SUPPORT
PROBE COIL

figure 3

6-DEC-1990 13:14

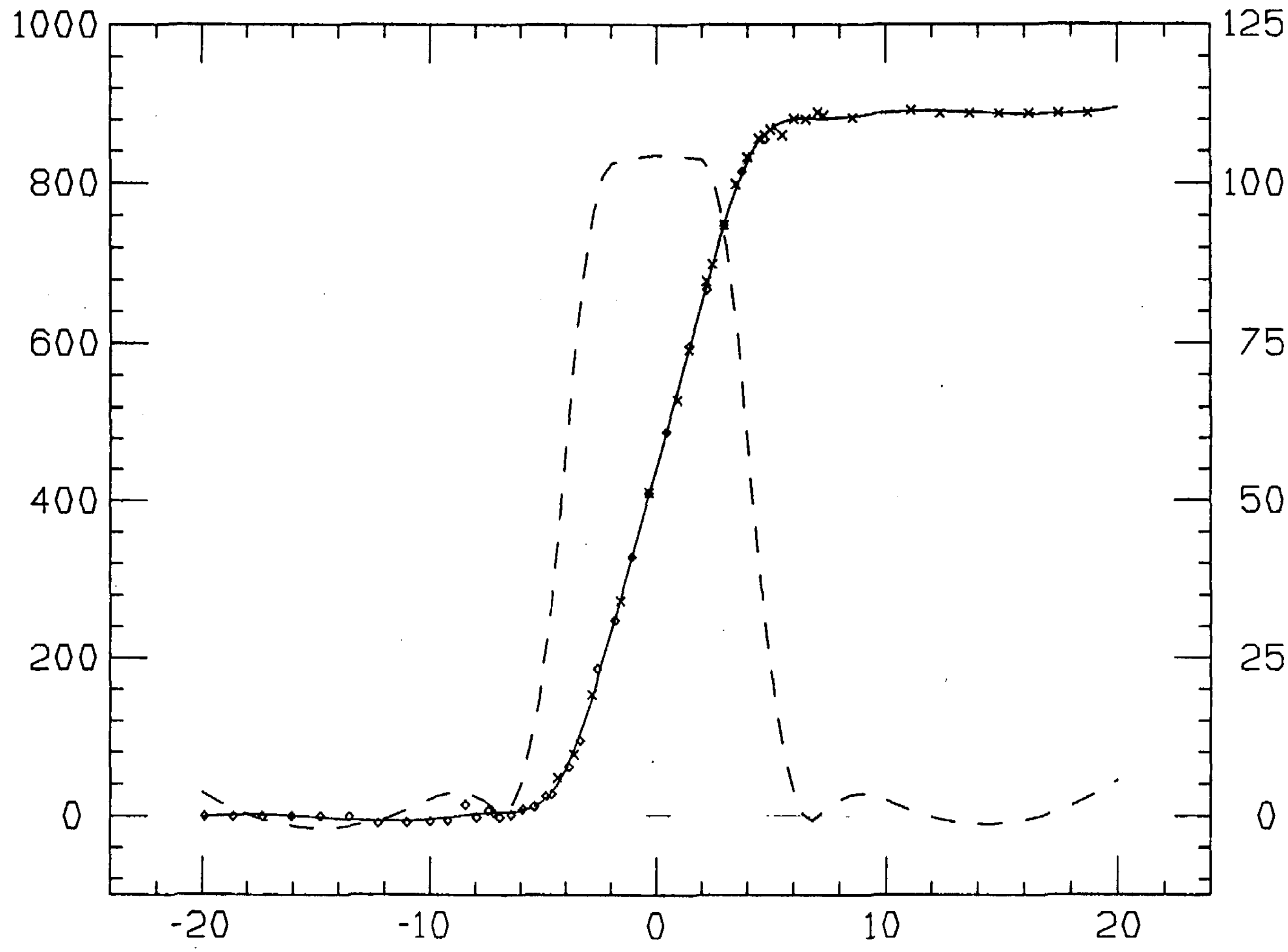


figure 4

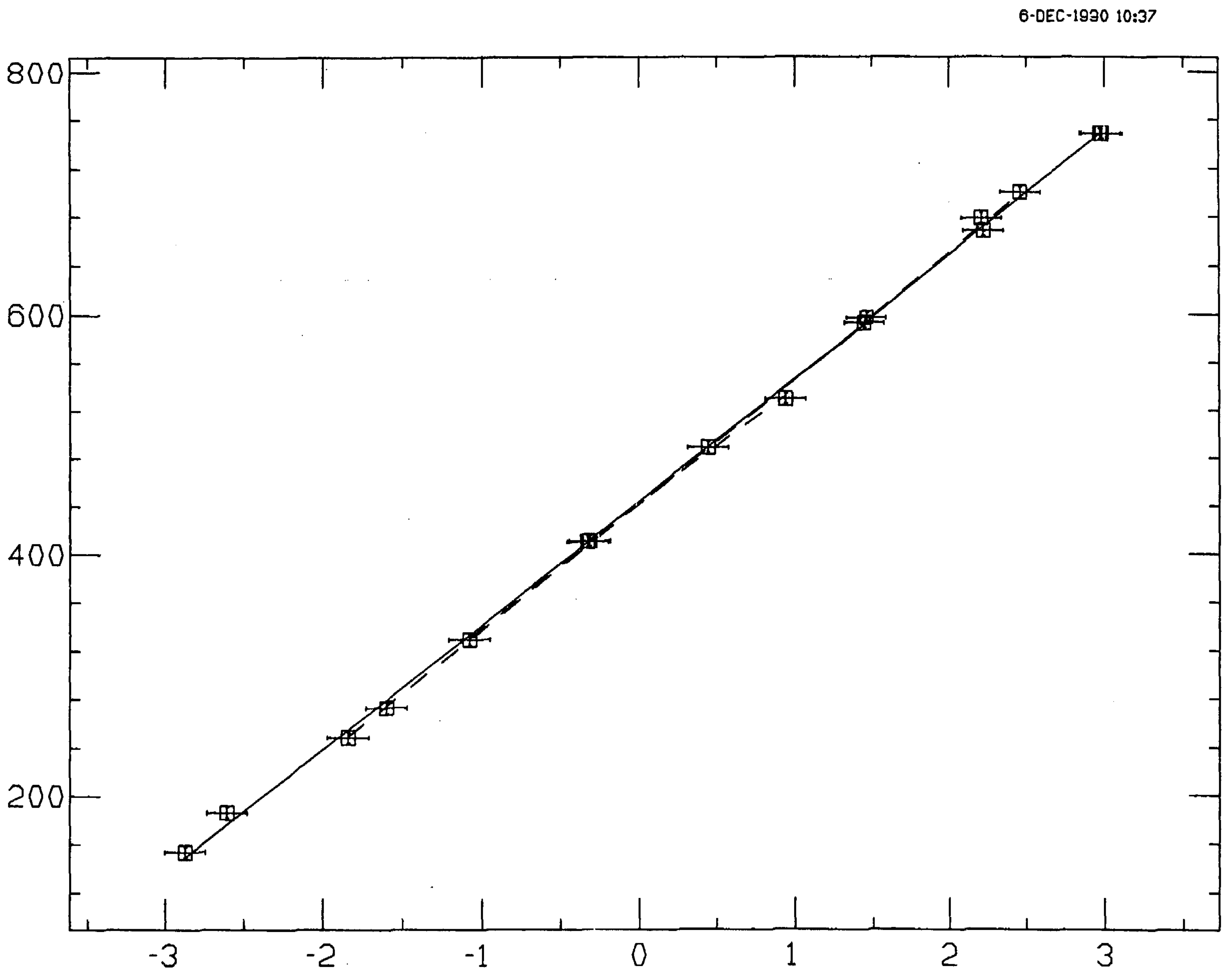


figure 5

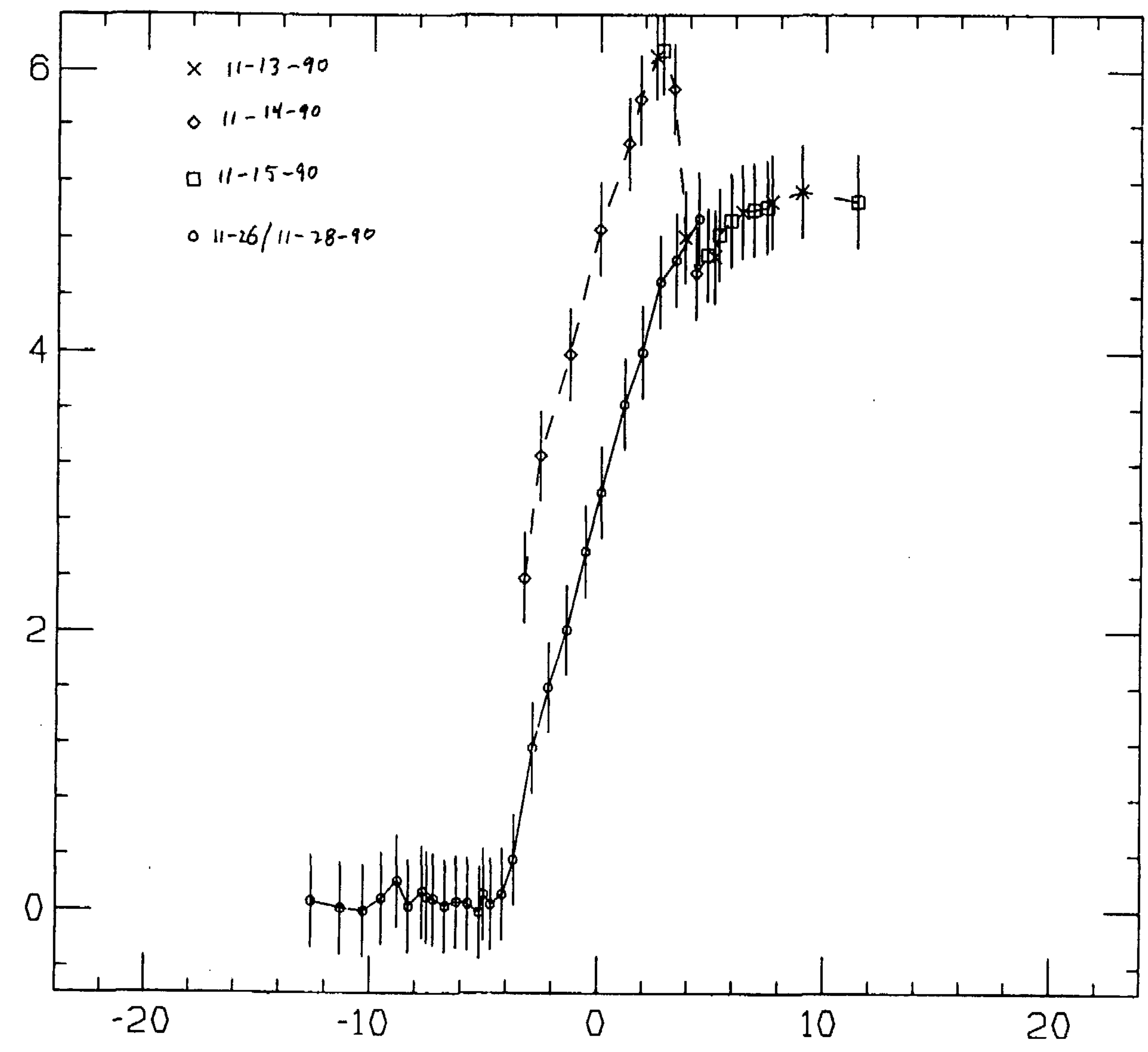


figure 6

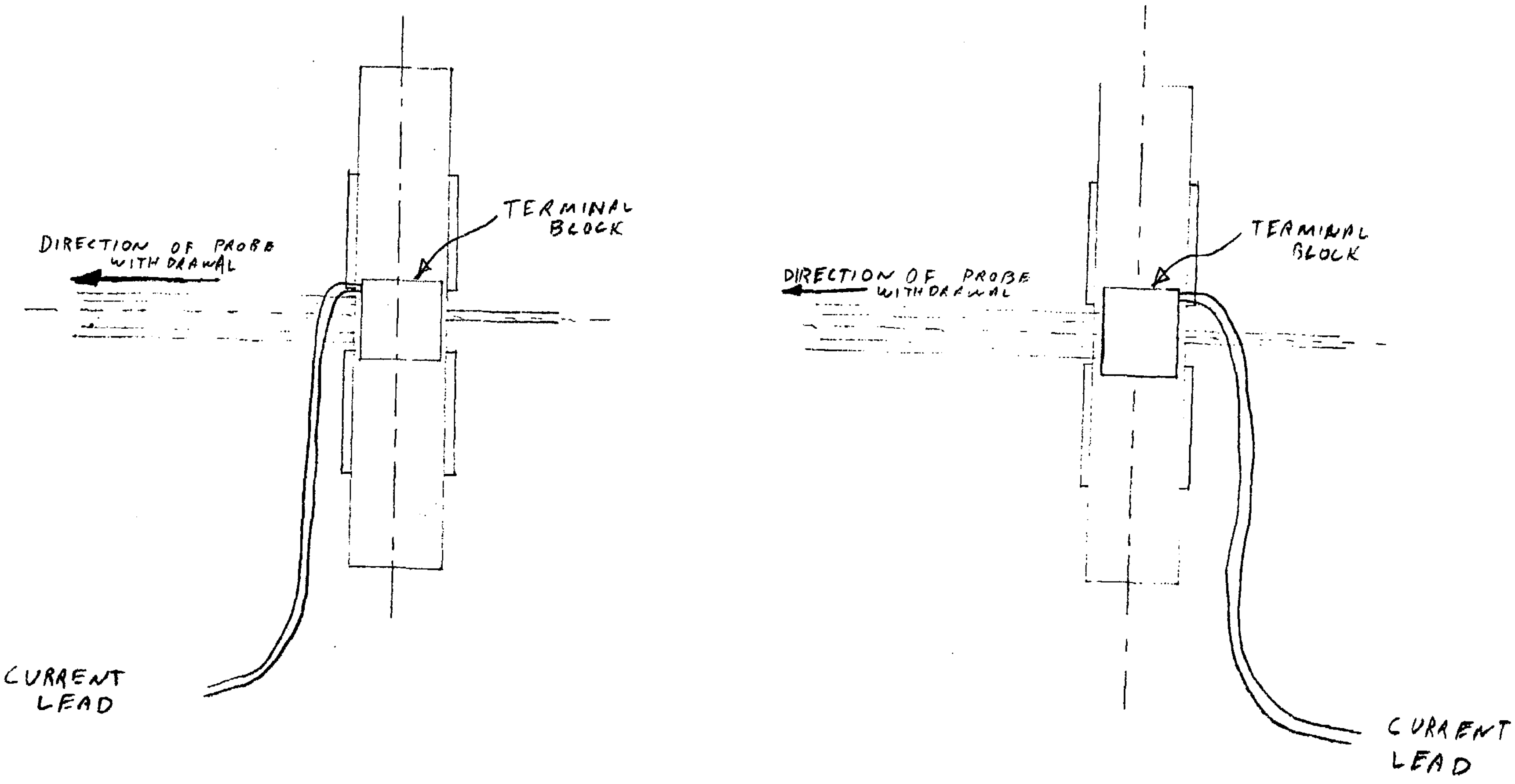

DIRECTION OF PROBE WITHDRAWAL
TERMINAL BLOCK
CURRENT LEAD
DIRECTION OF PROBE WITHDRAWAL
TERMINAL BLOCK
CURRENT LEAD

Figure 7

5-DEC-1990 11:43

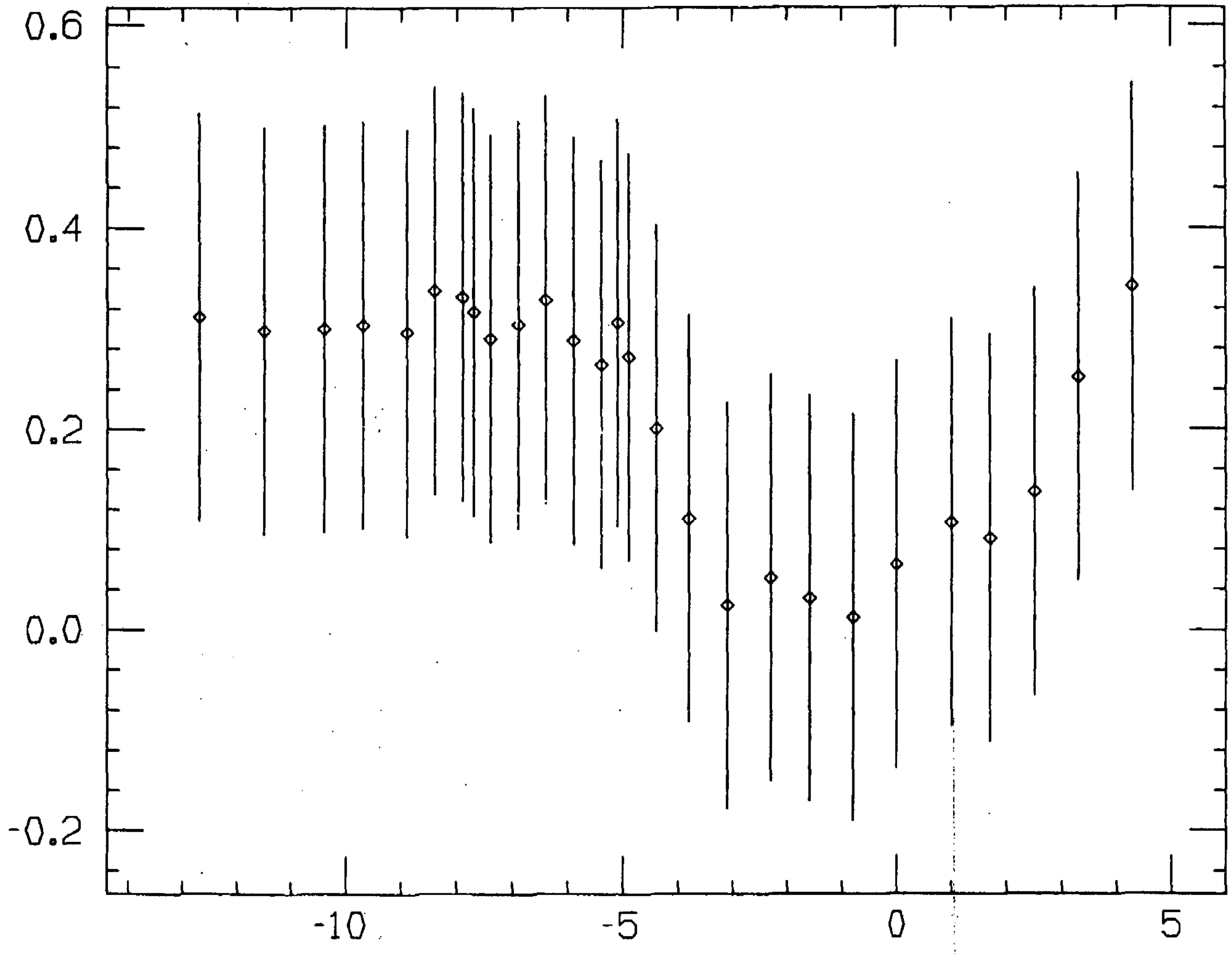


figure 8

Table 1

NRM1A.DAT NRM1B.DAT NRM1C.DAT
CURRENT -170.2 QUAD STRENGTH 889.72E-6 VOLT-SEC (WEBERS)

FFT HARM	/POLE	DIPOLE COIL	QUAD COIL	6-POLE COIL	8-POLE COIL	10-POLE COIL	12-POLE COIL	14-POLE COIL
1	2	96.	11.	0.	0.	0.	0.	0.
2	4	150.	10000.	11.	5.	7.	1.	6.
3	6	58.	20.	58.	0.	0.	1.	1.
4	8	12.	16.	1.	4.	2.	1.	1.
5	10	15.	6.	1.	2.	6.	1.	1.
6	12	6.	55.	1.	0.	3.	56.	1.
7	14	3.	3.	1.	2.	1.	1.	3.
8	16	18.	6.	1.	1.	1.	0.	0.
9	18	22.	13.	1.	1.	1.	1.	1.
10	20	19.	15.	1.	2.	2.	1.	1.
11	22	16.	18.	1.	3.	2.	1.	1.
12	24	2.	17.	1.	4.	2.	1.	1.
13	26	7.	20.	1.	3.	2.	1.	1.
14	28	19.	43.	1.	1.	0.	1.	0.
15	30	21.	7.	2.	2.	2.	2.	2.
16	32	12.	9.	2.	2.	2.	1.	1.
17	34	34.	5.	2.	1.	1.	3.	3.
18	36	28.	96.	3.	2.	1.	2.	2.
19	38	17.	18.	2.	2.	1.	2.	1.
20	40	20.	5.	1.	9.	6.	1.	1.
21	42	16.	21.	2.	2.	2.	2.	1.
22	44	27.	18.	0.	4.	3.	4.	3.
23	46	12.	16.	5.	3.	2.	3.	3.
24	48	14.	16.	3.	7.	5.	3.	3.
25	50	22.	12.	3.	2.	2.	3.	3.
26	52	13.	8.	4.	4.	3.	1.	1.
27	54	5.	4.	2.	5.	3.	2.	2.
28	56	17.	23.	5.	1.	1.	3.	3.
29	58	14.	3.	4.	7.	4.	1.	1.
30	60	16.	27.	1.	2.	2.	1.	1.

FFT HARM	/POLE	DIPOLE COIL	QUAD COIL	6-POLE COIL	8-POLE COIL	10-POLE COIL	12-POLE COIL	14-POLE COIL
1	2	153.	17.	0.	0.	0.	0.	0.
2	4	150.	10000.	11.	5.	7.	1.	6.
3	6	37.	12.	36.	0.	0.	0.	0.
4	8	5.	6.	0.	2.	1.	0.	0.
5	10	4.	2.	0.	1.	2.	0.	0.
6	12	1.	9.	0.	0.	0.	9.	0.
7	14	0.	0.	0.	0.	0.	0.	0.
8	16	1.	0.	0.	0.	0.	0.	0.
9	18	1.	1.	0.	0.	0.	0.	0.
10	20	0.	0.	0.	0.	0.	0.	0.
11	22	0.	0.	0.	0.	0.	0.	0.
12	24	0.	0.	0.	0.	0.	0.	0.
13	26	0.	0.	0.	0.	0.	0.	0.
14	28	0.	0.	0.	0.	0.	0.	0.
15	30	0.	0.	0.	0.	0.	0.	0.
16	32	0.	0.	0.	0.	0.	0.	0.

Table 2

```
CHISQ              0.01387 FOR     1 D.O.F
     -0.5000000000         0.5000000000
    443.7477678    +/-     2.449472787         0.0000000000E+00
    101.8428051    +/-     6.640161772         0.9999705200
CHISQ              0.01387 PER D.O.F
   MULT CORR        0.9999705200     FTEST    16959.8783127816
CL          0.90625
```

$L_{eff} = 8.72$

```
CHISQ              1.43896 FOR     2 D.O.F
     -1.0000000000         1.0000000000
    442.4630534    +/-     2.200397955         0.0000000000E+00
    95.40792638    +/-     3.877574467         0.9988136934
CHISQ              0.71948 PER D.O.F
   MULT CORR        0.9988136934     FTEST      841.4526817727
CL          0.48701
```

$L_{eff} = 9.31$

```
CHISQ              7.10195 FOR     5 D.O.F
     -1.5000000000         1.5000000000
    442.1452477    +/-     1.697876115         0.0000000000E+00
    103.2719412    +/-     1.738934525         0.9989947036
CHISQ              1.42039 PER D.O.F
   MULT CORR        0.9989947036     FTEST     2483.0793090587
CL          0.21317
```

$L_{eff} = 8.60$

```
CHISQ              7.65288 FOR     7 D.O.F
     -2.0000000000         2.0000000000
    441.4375566    +/-     1.393894105         0.0000000000E+00
    104.1970990    +/-     1.176186090         0.9995127877
CHISQ              1.09327 PER D.O.F
   MULT CORR        0.9995127877     FTEST     7178.4778186700
CL          0.36420
```

$L_{eff} = 8.53 \pm .10$

```
CHISQ             11.75095 FOR    10 D.O.F
     -2.5000000000         2.5000000000
    441.6615686    +/-     1.271601127         0.0000000000E+00
    104.5282149    +/-   0.8251194826          0.9996340926
CHISQ              1.17510 PER D.O.F
   MULT CORR        0.9996340926     FTEST    13657.1586609052
CL          0.30207
```

$L_{eff} = 8.50$

```
CHISQ             25.05861 FOR    14 D.O.F
     -3.0000000000         3.0000000000
    443.7250680    +/-     1.064751605         0.0000000000E+00
    102.5832683    +/-   0.5441785805          0.9996476071
CHISQ              1.78990 PER D.O.F
   MULT CORR        0.9996476071     FTEST    19853.6930377619
CL          3.39932E-02
```

$L_{eff} = 8.66$